Public-data File 86-55

NORTHWEST ALASKA COAL INVESTIGATION

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December 1986

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EXECUTIVE SUMMARY

As part of the Northwest Coal Investigation program funded by the State of Alaska and coordinated by the Division of Geological and Geophysical Surveys, C. C. Hawley and Associates, Inc. was contracted to evaluate three coal occurrences in the Kotzebue and Norton Sound areas of western Alaska.

Chicago Creek, a lignitic coal deposit which is a potential alternative energy source for Kotzebue, supported a small mine at the turn of the century with a total production of approximately 100,000 tons. The deposit consists of a single seam which averages 35 feet in thickness, strikes generally north, and dips approximately 45 degrees to the west.

The 1983 program added 2,800 feet of rotary drilling information, over 13,000 feet of useful surface geophysics, and geologic mapping. From this information, a new model for the coal deposit is developed which could have important implications for further exploration.

A geophysical reconnaissance program was designed to test the merits of several geophysical techniques for distinguishing coal in the permafrost environment. The program indicated that, of the three techniques tested, the magnetometer survey showed the best correlation to the coal-bearing sequence.

Resource estimates indicate a 3.4 million ton demonstrated resource exists, and interpretive geology suggests an additional inferred resource of 1 million tons.

Preliminary mine feasibility suggests that Chicago Creek has a good chance of becoming economic. At this preliminary stage, to be competitive, it appears that a Chicago Creek mine must be able to deliver coal to Kotzebue for about $85/ton. Past cost estimates, and one completed for this study, indicate that this may be feasible; however, further detailed mining engineering needs to be completed before the feasibility of a mining operation can be assured.

Exploratory drilling at the Koyuk and Unalakleet sites determined that coal occurrences were thin (less than three feet), deeply buried, and laterally discontinuous. Although economic recovery of these occurrences does not appear feasible, geologic inference suggests that other areas near the communities of Koyuk and Unalakleet may be more favorable for thicker, more continuous coal deposits.

I. INTRODUCTION

The coal investigations described herein are part of a five year effort by the State of Alaska to define alternative energy sources for rural Alaska. During the late 1970's and early 1980's, several programs were funded to seek new sources of energy and suggest innovative methods of using traditional fuels in remote regions. These studies covered widely scattered areas of Alaska, including Kotzebue and the Norton Sound areas. They addressed such sources as wind, geothermal, hydroelectric, coal, peat, wood, and natural gas. They considered more efficient designs of fossil fuel generation plants, including waste heat recovery and biomass conversion. One of the many conclusions drawn from these studies suggested that coal could be a cost-effective alternative for the Kotzebue Sound area (R. W. Retherford & Associates, 1980).

In 1980 the State began to focus their efforts on better identification of critical resources such as coal. Initially, a program funded by the Alaska Power Authority compiled all known information on coal resources within northwestern Alaska (Dames and Moore, 1980). In following years the Department of Geological and Geophysical Surveys (DGGS) selected some of the more important coal deposits to be investigated in more detail. Field work included rapid reconnaissance surveys, as well as drilling and mapping programs.

Areas included the western North Slope (Kukpowruk, Corwin Bluffs, and Cape Lisburne), the Kobuk River, the coals of the Kugruk River, and occurrences on Norton Sound. This report is a continuation of a drilling exploration program begun by Denali Drilling in 1982 (Stevens, 1982). Coal occurrences at Chicago Creek on the Kugruk River and near Koyuk and Unalakleet (on Norton Sound) were explored during this program (Figure 1).

The objectives of the program as outlined in RFP 9216 were as follows: At Chicago Creek, determining the northern extent of the known coal bed was considered to be of primary importance. Of secondary importance was a search at the south end of the deposit for the bed where it was apparently offset by a fault. Coal reserves were to be calculated and a preliminary mine plan designed. At Koyuk and Unalakleet the deposits were less well defined, so the primary objective was to locate and define any coal beds and then to characterize them. Initially, the program included a reconnaissance drilling program near Grouse Creek (approximately 30 miles west of Koyuk); however, this part of the program was eliminated for budgetary considerations.

Base map adapted from USGS 'Map E'

Project Area Index Map

Figure 1

The scope of work at Chicago Creek called for 2,000 feet of rotary drilling, combined with downhole geophysical logging of the borehole. In addition, a surface geophysical program was requested to test the merits of various techniques for exploration of covered coal beds in permafrost terrain.

During the 1983 field program at Chicago Creek, 14 rotary holes were drilled, totaling 2,800 feet. Eleven of the holes (or 2,218 feet) were geophysically logged. The surface geophysical program tested three techniques: 1) shallow seismic reflection (2,400 feet of line), 2) a new dual frequency EM system developed by Scintrex (11,000 feet of line), and 3) a magnetometer survey (13,500 feet of line).

The scope of work at Koyuk included a contracted amount of 1,150 feet of drilling. This included core sampling in five holes contingent upon finding a suitable bed to be sampled. All holes were to be logged geophysically, but no surface geophysics were planned. At the Koyuk site, a total of 1,440 feet was drilled and logged in 12 rotary holes. As very little coal was encountered, only one core hole was attempted with poor recovery.

The contracted amount of drilling for the Unalakleet site was 1,500 feet. Similar to Koyuk, this total included core sampling in five holes if a suitably thick bed was encountered. The Unalakleet phase of the project was more exploratory in concept than Chicago Creek or Koyuk, and primary emphasis was placed on searching for possible coal beds over a broad area. Actual 1983 field work at Unalakleet produced 12 geophysically logged rotary holes totaling 1,820 feet. As at Koyuk, the few coal intercepts were thin and laterally discontinuous, so no coring was attempted.

II. METHODS OF INVESTIGATION

A combination of geologic mapping, drilling, and geophysical surveying was employed to aid in the evaluation of coal resources of the three areas.

A. Geologic Mapping

Surface geologic mapping is limited by exposure in all three areas. The Koyuk site is almost entirely covered and featureless; the Unalakleet site provided good beach exposures. The Chicago Creek site itself contained almost no exposures, but bedrock outcrops were mapped downstream. At Unalakleet, the beach exposures show that the coal is in thin lenses and pods which formed in a high energy deltaic environment--an environment unsuitable for the formation of thick, continuous coal seams. At Chicago Creek, several exposures of steeply dipping metasediments to the west of the coal deposit provide evidence of the folding that has taken place.

Aerial reconnaissance shows a general geomorphic depression to the north of Chicago Creek, suggesting that the coal-bearing sediments may carry through toward Willow Bay.

B. Drilling Program

The primary means of acquiring subsurface data for the Northwest Coal investigation was a rotary drilling program combined with lithologic logging of the cuttings and comprehensive geophysical logging of the borehole. The drill was a Mayhew 1000 air-rotary rig mounted on a Yukon tracked carrier. The drilling subcontractor was Thrasher & Associates of Nome.

Holes were drilled with 4 3/4" drag and tricone bits. In order to provide large cuttings suitable for lithologic description, drag/insert bits were used whenever possible. Strongly indurated formations required the use of tricone bits.

Rotary cuttings were caught as a continuous sample, then broken into 5-foot increments for lithologic description. Coal cuttings were bagged, sealed, and shipped to the Mineral Industry Research Laboratory in Fairbanks for analysis.

The standard geophysical log suite for the investigation consisted of natural gamma, density, and caliper logs. Drill hole #6 at Chicago Creek was logged with a multi-channel sonic tool to determine formation velocities, in addition to the standard suite of logs in both dry and fluid filled, uncased conditions. All other boreholes were logged dry and uncased. The fluid filled borehole provided a calibrated log for precise density measurements; however, log response and resolution in the dry holes was excellent. All lithologies are easily identified on the logs. Prompt geophysical logging of the borehole with properly calibrated instruments insured adequate log response. The geophysical logging subcontractor was British Plasterboard (B.P.B., Inc.) from Grand Junction, Colorado.

C. Surface Geophysics

The surface geophysical program at Chicago Creek was designed to test the response of seismic reflection, EM, and magnetic techniques over an area known to be underlain by coal. A complete discussion of the geophysical program is included in Appendix A.

Seismic reflection can be expected to be valuable in discerning velocity contrasts between the coal and associated strata. Reflection seismics can also penetrate high velocity near surface massive ice layers likely to be present. Although steeply dipping strata make interpretation of reflection data difficult, previous drilling information suggested that the coal unit would flatten with depth. Velocity stratification would be provided by seismic refraction and down-hole sonic logs which would allow for more accuracy in the interpretation of the reflection data. For the seismic reflection technique to be effective, simple and consistent velocity relations among reflectors must be present. The results of the downhole sonic logs, however, showed an extremely busy profile with multiple reflectors. These reflectors, which were confirmed upon attempting actual reflection surveys, probably represent complex ice lensing throughout at least the upper 50 feet of surface material and effectively negate the use of reflection seismic technique.

Based on limited correlation of stratigraphy with the EM data collected during the 1982 investigations, it was expected that a slightly more sophisticated EM system could gather still better information. Thus, a relatively new system was selected with greater depth penetration. The results of the 1983 EM survey, however, were disappointing showing a very low level of response.

The magnetometer survey was included in the geophysical program primarily as a method for locating and tracing the suspected fault in the southern portion of the study area. It also was considered possible that the magnetic susceptibility contrast between the coal and the other associated units could be sufficient to provide a recognizable signal under favorable conditions. The magnetometer survey, somewhat surprisingly, showed quite good response with excellent correlation with the known stratigraphy.

III. GEOLOGIC INVESTIGATIONS

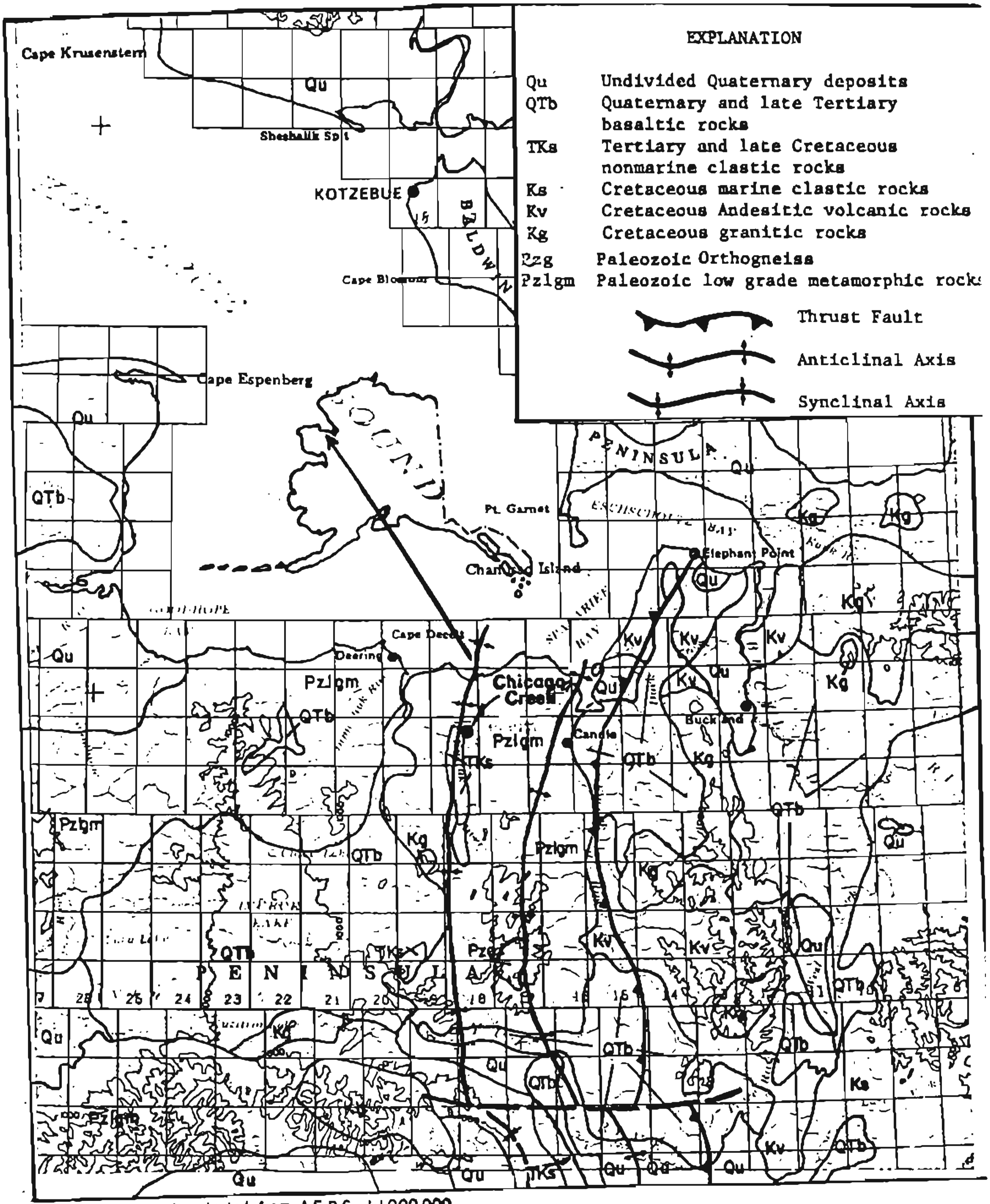
A. Chicago Creek

Introduction

The Chicago Creek coal deposit consists of a single main coal bed with a maximum true thickness of approximately 80 feet and an average thickness of 35 feet. The bed generally strikes north and dips steeply to the west. The coal is ranked as lignite and has an averaged British thermal unit (Btu) rating of 6987 on an as-received basis (Stevens, 1982). Proximate analysis of the coal indicates 35.58% moisture, 26.28% volatile matter, 30.86% fixed carbon, 7.28% ash (although parts of the bed contain as much as 17% ash) and .97% sulfur (Stevens, 1982).

Location

The Chicago Creek coal occurrence is on the northeastern corner of the Seward Peninsula, about 15 miles southeast of Deering and 14 miles west of Candle (Figure 2). The site of the old Chicago Creek mine is located about 1.25 miles east of the confluence of Chicago Creek and the Kugruk River, a north-flowing river which drains into Kotzebue Sound.



Regional Geology and Index Map - Chicago Creek, from Hudson 1977, Patton 1973, Till et al 1983

Figure 2

Access

The drilling and logging equipment used at the Chicago Creek site was flown in by Hercules aircraft to the 5,000-foot airstrip at Candle. There is an established cat trail system between Candle and the project area, and the equipment was walked overland to the site. Support transportation of men and equipment during the study was handled by Bombardier tracked carrier and three-wheel all terrain cycle.

Operations were based out of an established placer camp on the Kugruk River, approximately 1.5 miles from the project site (presently leased by Virgil Vial, Candle, Alaska). There is a 1,200-foot gravel airstrip at the camp, and personnel and supplies were flown in by single Otter, Beaver and Cessna 206 aircraft from Nome.

History

Coal on Chicago Creek was discovered by gold prospectors in 1902 (Moffit, 1906). Some development work was done in the year of discovery, but there was little demand for the coal until the winter of 1904-05 when gold was discovered on the terraces above Candle Creek and the need arose for a source of low cost heat for steam-thaw mining methods. The Chicago Creek coal mine began production in 1908 in response to this demand. This was not a long-term market, however, as the mine was abandoned in 1911.

The mine was operated during the winter months only; during the summer it was sealed, probably to prevent thawing around the adit. Henshaw (1909) visited the property. He noted that the inclined shaft was approximately 330 feet long, sloped at an angle of 18 to 36 degrees and reached a depth of 200 feet. The coal was solidly frozen to that depth. Apparently the mine was being worked at four levels which were 33, 80, 100, and 144 feet below the shaft house. He observed that the part of the bed worked on the lowest level produced the most uniform coal; however, a portion of the seam within 20 feet of the hanging wall also yielded good quality coal.

Previous Investigations

A great deal of the turn-of-the-century interest in the Chicago Creek coal mine was undoubtedly linked to providing energy for gold mining operations. Many of the U. S. Geological Survey publications that dealt with the Seward Peninsula during the 1900's reported on the progress of coal mining in the Chicago Creek area. Geologists that authored these articles included Moffitt, Henshaw, and Smith.

The Chicago Creek occurrence received very little attention until fuel oil increased drastically in price in the 1970's, and again spurred an interest in local energy alternatives. A report by the Bureau of Mines (Toenges and Jolley, 1947) offered the first detailed preliminary mine plan for the deposit. Finally, in 1982, the exploration effort by Denali Drilling, Inc. and Stevens Exploration Management Corporation provided a much broader view of the extent, geology, and structure of the deposit.

Regional Geology -- Chicago Creek

Stratigraphy

In the northeastern part of the Seward peninsula much of the basement consists of a low grade metamorphic complex of probable Paleozoic age (Pzlgm--Figure 2). The composition of this unit ranges from chlorite-rich metapelite in the lower section to interlayered graphitic metaquartzite, micaceous marble and minor metapelite in the middle section to chlorite and albite schists with lenses of metabasite in the upper section (Till, 1983). This sequence of rocks is often referred to as the "York slate" or the Nome group and has in the past been considered Precambrian in age (Sainsbury, 1974). Recent work by Till, however, suggests that these rocks are probably closer to mid Paleozoic and are possibly early Devonian in age.

On the eastern edge of the Seward Peninsula, this crystalline basement is juxtaposed against and locally overlain by a series of limestone, shale, siltstone, graywacke, nonmarine conglomerate, and coal of Cretaceous age (Patton, 1973). This sequence is the western fringe of the northern Yukon-Koyukuk province, a complex and mobile tract of Cretaceous and Tertiary volcanic and sedimentary rocks (Ks and Kv--Figure 2) which occur in a wedge-shaped, basin-like depression east of the Seward Peninsula (Patton, 1973). According to Patton, remnants of these coal-bearing sediments occur in structural depressions within the metamorphic terrane on the eastern Seward Peninsula.

The Spruce Creek Formation, a limestone and schist cobble conglomerate of Cretaceous age which occurs along the eastern Darby Mountains and the headwaters of the Kugruk River, and an unnamed sequence of interbedded graywacke sandstone, shale and siltstone which occurs near the headwaters of the Kugruk are examples of some of these remnants (Sainsbury, 1974). These units appear on the south-central part of Figure 2 but, due to the scale of the map, are included in the "TKs" unit.

To the north, along the Kugruk River, medium to dark gray sandy and shaly limestone with coal fragments occur which are also assigned to the Cretaceous, but age dates for this unit are tentative (Sainsbury, 1974). This sequence is also designated "TKs" on Figure 2 and is shown on Plate 1 to the west of the coal seam. These rocks are probably somewhat younger than the Spruce Creek Formation and associated sediments mentioned above. They are possibly equivalent to the shale and siltstone sequence which encloses the Chicago Creek coal bed.

The Cretaceous sedimentary rocks along the Kugruk, as well as other sequences on the Seward Peninsula assigned to late Cretaceous/early Tertiary, are complexly deformed and are commonly buried by surficial deposits and locally overlain by Tertiary to recent basalt flows. Their exact distribution and relation to the basement is, therefore, generally uncertain.

The coal seam at Chicago Creek has been given a tentative age of Late Cretaceous from fossil determinations of broad leaf plants, but it may be as young as Early Tertiary (Sainsbury, 1974). The lignitic character of the bed indicates that it may indeed be Tertiary. The Mississippian coals of Cape Lisburne range from bituminous to semianthracitic, Cretaceous coals of the Beaufort area tend to be subbituminous to bituminous, while Tertiary coals on the Seward

Peninsula are generally lignitic (Dames and Moore, Resource Associates of Alaska, 1980).

Tertiary coal-bearing sediments on the Seward Peninsula generally occur as flat lying, poorly- to well-consolidated gravel, sand, silt, carbonaceous debris, and lignitic coal beds. These strata were primarily deposited in tectonically controlled basins and vary in thickness from 3,000 to 9,000 feet (Dames and Moore, Resource Associates of Alaska, 1980). Though coal occurrences have long been recognized, the extent of some of the Tertiary basins on the Seward Peninsula was not understood until recently. Uranium exploration by private industry in the late 1970's prompted drilling programs to evaluate many of the sedimentary basins on the peninsula. This activity resulted in recognition of many of the alluvial flats such as McCarthy's Marsh (Qu--southwest Figure 2) and Death Valley (Qu--southcentral Figure 2) as large coal-bearing Tertiary basins (Dames and Moore, Resource Associates of Alaska, 1980).

Structure

In Late Cretaceous or Early Tertiary time, eastward directed compressional forces began to develop north-south oriented structural trends on the eastern Seward Peninsula. Downwarped areas provided locales for Late Cretaceous to Early Tertiary basin development and coal deposition. Continual compression from the west resulted in the formation of a fold belt known as the Lisburne-Seward trend. This belt stretches from Cape Lisburne down the east side of Kotzebue Sound through the eastern side of the Seward Peninsula (the Collier Thrustbelt) and eastern Norton Sound. It is reflected in the Cape Lisburne area and on the Seward Peninsula by the development of north-south trending anticlinal/synclinal folds (Figure 2) and the eastward thrusting of Paleozoic strata onto Mesozoic rocks (Patton, 1973).

Project Area Geology

Stratigraphy

The coal at Chicago Creek is generally underlain by schistose metasedimentary rocks. The main coal bed is overlain by shale and siltstone which is overlain by surficial deposits of ice and frozen silt.

The deposit has been subdivided into numbered segments on Plate 1 for description of specific areas in the text.

The Basement Complex: The metamorphic unit which comprises the basement complex consists of light silvery gray to green locally micaceous, chloritic, or graphitic schists and phyllite with occasional quartzite. The upper surface of the metasedimentary rocks has weathered to a light gray to green saprolite to a depth of approximately 20 feet. In the central portion of the project area (Segments III through VA) this material was apparently the depositional surface for the coal as, for the most part, the seam rests unconformably on this weathered horizon. Examples of this can be seen in the geophysical and lithology logs for DH-7-83, 8-83 and 9-83. (On the geophysical logs the metasedimentary rocks can be identified by a very high density, very low gamma response occurring at, for example, 162 feet in DH-7-83.)

In the southern portion of the project area in the vicinity of the old mine (Segment I) the coal is described by Stevens (1982) as being underlain by a light gray underclay from 2 to 10 feet thick. It is speculated that this is also the weathered surface of the metasedimentary rocks as the schist and phyllite intercepted by C. C. Hawley and Associates, Inc. drill holes just to the north is light silvery gray in color.

In Segments II and VB the main coal seam is underlain by a series of interbedded medium gray to dark brown shale, siltstone and lenses of coal. This sequence is underlain unconformably by the weathered metasedimentary rocks.

Overlying Sediments: The coal is immediately overlain by dark brown to medium gray occasionally light colored shale and siltstone. This unit is locally carbonaceous, contains very little sand or clay, and is generally frozen with occasional ice lenses. To the north these strata exhibit pencil cleavage. This sequence is overlain by unconsolidated surficial deposits of frozen silt and loess which varies from 10 to 30 feet in thickness. Local ice wedges occur to 50 feet in thickness.

In Segment VA and VB starting with DH-7-83 and continuing to the north there is a unit in contact with the roof of the coal seam and labeled on Plate 2 as "roof clay". Although this unit does not appear to contain a greater amount of clay than the shale-siltstone sequence it is labeled as roof clay because of the higher gamma response which identifies it on the geophysical logs.

The Coal: As mentioned above, the Chicago Creek coal seam is a locally thick bed ranked as lignite. Measurements of the bed taken by Henshaw in 1908 indicate a true bed thickness of 88 feet and 85 feet at two locations in the old mine workings. This section included some minor, very thin partings of bone and sandy shale; however, this maximum thickness and lack of significant partings does not occur extensively along strike. Henshaw also observed that the coal was frozen and much of it tends to crumble and reduce to fines when removed from the mine and thawed. Other workers have often noted that the seam is highly fractured. Stevens observed a well devéloped face and butt cleat pattern in core samples from the 1982 investigation.

The coal reserves are contained in a single seam which has a known strike length of aproximately 8,000 feet. The seam is truncated just south of Chicago Creek by a probable east-west trending fault (Stevens, 1982). North of this, in Segment I the seam reaches its maximum thickness. This is the general area of the old mine workings. The mine adit entered the seam on the south side of Chicago Creek and the workings were developed to the south.

A north-south longitudinal section of the project area is presented on Plate 2. It should be noted that this is an "idealized" cross-section as there are some inconsistencies when projecting data from holes which do not lie in the plane of section.

In Segment II, the seam begins to split into several benches separated by clay partings. Progressively to the north the benches thin and the partings increase in size and number, the bed becoming dirtier until it essentially pinches out. In Segment III between DH-11-82 and DH-13-82 there are no coal beds; however, there are occasional zones with numerous coal fragments. To the north in the vicinity of DH-13-82 several very thin coal seams began to show up interbedded with sand, silt and clay. Apparently, Segment III represents an area of relative high energy or alluvial deposition during the time of adjacent coal deposition, probably a small sluggish stream (stippled area--Plate 2--DH-3-83). Partings extending into the seam from this area are probably overbank deposits of silt, clay and minor sand during flood excursions of the stream out of its traditional channel. This does not appear to be a washout in the sense of a post-coal deposition erosional phenomenon, as the main seam thins and splits from both the north and south into this locale.

Beginning with DH-13-82 in Segment IV the coal progressively thickens to the north with an average thickness of 28 feet. In Segment VA, however, DH-9-82 intercepted only 5 feet of coal. It appears that the seam has thinned in this area but a very likely explanation is that the drill hole has intercepted the eastern fringe of the subcrop. Since the seam dips 45 degrees to the west in this area, as one moves eastward across the angular unconformity between the subcropping coal and the surficial deposits, the convergence of the relatively horizontal erosion surface and the 45 degree base of the seam would present a progressively thinning coal intercept. Moving to the north through Segments VA and VB the seam averages about 30 feet in thickness.

Although DH-14-83 did not intercept coal (stopped at 198 feet due to mechanical difficulties) drilling ceased in the shale-siltstone sequence which overlies the coal to the south. Log correlations through this sequence indicate that the top of the bed would probably have been intercepted at 220 feet. There is no indication that the seam does not continue to the north.

Structure

Generally the coal bearing strata dip steeply to the west and strike to the north. In the area of the old mine workings (Segment I) various workers have cited dips that range from 53 degrees to 72 degrees to the west. This discrepancy in angles could possibly be explained by the fact that locally the dip of the bed appears to progressively flatten from top to bottom in the bed. Through core drilling in 1982 Stevens found that the dip flattened from approximately 70 degrees in the upper part of the unit to approximately 50 degrees in the lower part of the unit.

North of the old mine workings the dip appears to be uniform throughout the bed and less steep than the upper part in Segment I. In Segment IV it has flattened to approximately 50 degrees and in Segment VB it flattens to 45 degrees.

As mentioned above, the strike of the seam is generally north. In Segment I the bed strikes N 6 degrees W (Stevens, 1982). To the north through Segment VA the strike generally swings closer to due north. In Segment VB between DH-10-83 and DH-11-83 there is a pronounced strike change to approximately N 14 degrees E. This phenomenon is probably the result of a low angle east-west trending anticlinal fold. This change in strike and the general trend of the bed is reflected in the magnetic anomalies found in the geophysical survey (Plate 4).

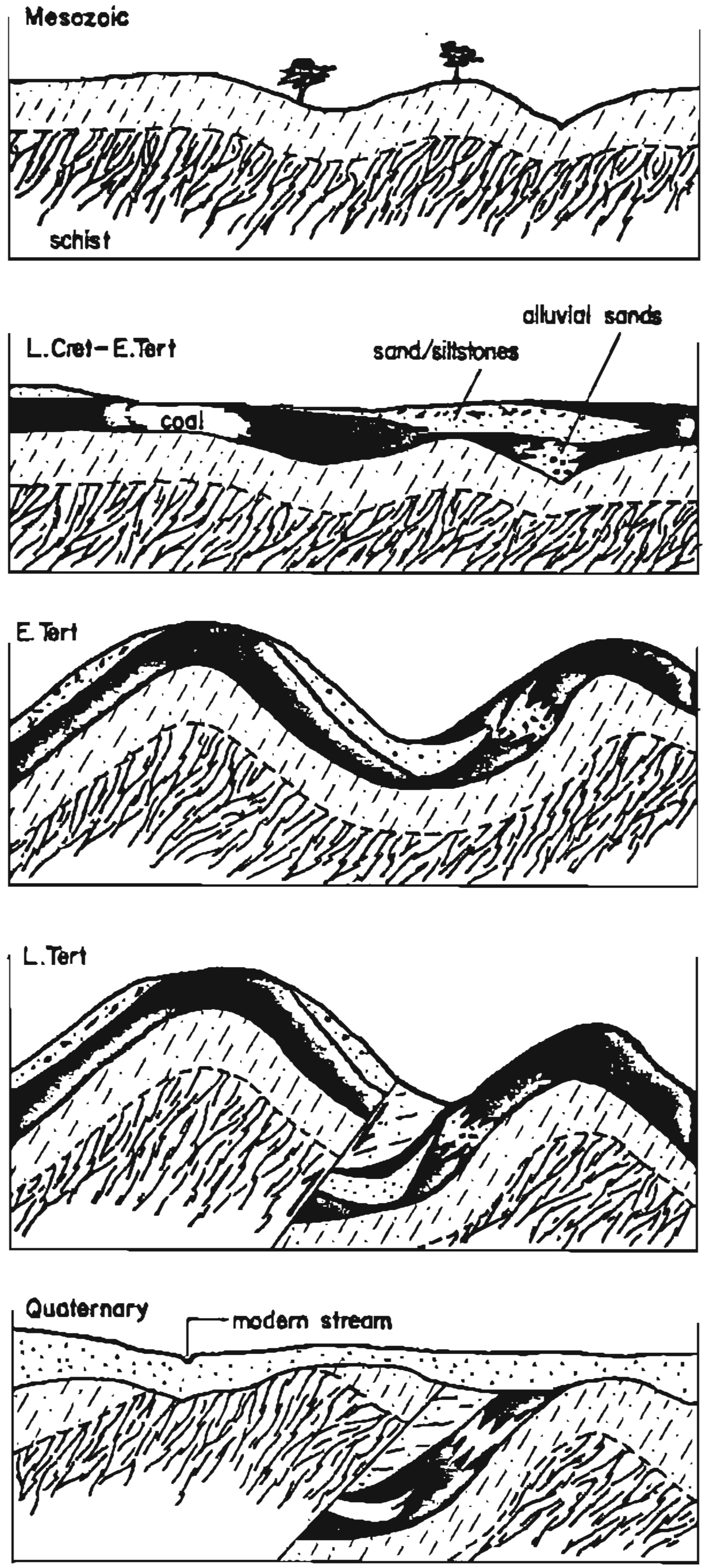
Generally the structural elements at Chicago Creek trend north-south. This is probably a result of the eastward directed compressional forces which were active on a regional scale during Tertiary time. It is speculated that this compression eventually warped the strata at Chicago Creek into north-south trending anticlinal/synclinal folds (Figures 2 and 3). Continued compression may have resulted in thrust faulting in the local area, as diagrammatically shown in Segments IV and V of Figure 3.

To the west the coal bearing strata are in contact with schistose metasedimentary rocks similar to those in the core of the proposed anticline. This may be the result of a thrust fault as shown in Figure 3. Similar thrusting of Paleozoic strata onto Mesozoic has occurred at Cape Lisburne to the north in the Lisburne-Seward structural trend.

Depositional Environment

Although a relatively limited portion of the Chicago Creek coal measure has been studied (particularly to the east and west), it can be speculated that the environment of deposition was fluvial, upper delta plain, possibly transitional to lower delta plain. This environment is characterized by locally thick coal which is laterally discontinuous in the upper delta environment progressing to thinner but more widespread coals in the lower delta plain.

Because the shallower parts of the bed are essentially structurally bounded, much more is known about the original environment from north to south than from east to west.



1 Irregular surface of weathered schist

2 Development of coal and other sediments

3 Compressional warping

4 Faulting

5 Erosion, then deposition of loess

Proposed Structural History of Chicago Creek Coals

Figure 3

In the central part of the project area between DH-3-83 and DH-10-83 (Segments IV and VA) there is a residual topographic high of basement rock indicated by the drill hole data (Plate 2). During the time that the earliest and stratigraphically lowest part of the Chicago Creek seam was being deposited in Segment I the area to the north in Segments IV and VA was dominated by this upland. This highland is the probable source of some of the detritus deposited on its flanks to the north and south, probably provided some of the drainage energy and sediment for the fluvial deposition in Segment III and generally made conditions inhospitable for plant growth (or preservation) and subsequent coal deposition in the immediate area.

North of this upland environment there appears to be the edge of another shallow basin with a hint of increasing coal content in stratigraphic interval below the main seam (apparent on geophysical logs for DH-11, DH-12 and DH-13-83). If this basin held the stable long lived (estimated to have been 13,000 years from seam thickness) coal forming environment exhibited to the south in Segment I, then there is potential here for similarly thick coal deposition.

The upland area was eventually subdued through erosion and basin filling to a more quiescent environment and subsequent coal forming plant growth progressed throughout the central and northern parts of the project area.

Resource Estimation

Combining the results of the 1982 and 1983 drilling programs, an estimation of the identified coal resource at Chicago Creek can be made. The term "resource" is used here rather than "reserve", as it is yet to be shown that the the deposit is economically viable (see Table 1 for definition of terms). Furthermore, in consideration of the quality and quantity of information available from a defined area at Chicago Creek, the term "demonstrated" seems an appropriate modifier of "resource". By definition, demonstrated resources include both measured and indicated resources. At Chicago Creek geologic information is best at the southern end of the deposit adjacent to the former mine, where a portion of the resource may be considered measured. The central and northern portions are delineated by drill hole information only and should be categorized as indicated.

Demonstrated resources were calculated for each of Segments I through VB (Plate 1). These segments, as discussed previously, were defined so that each one is relatively consistent in bed thickness. A mineable strike length was determined for each segment; this length, which was not necessarily the same as the total length of the segment, was interpreted from all subsurface information. Finally, a dip length was calculated for 100-, 200- and 300-foot mining depths. The depths were based on vertical distance below the subsurface outcrop,

TABLE 1

Partial Listing of 1980 U. S. Geological Survey
Coal Resource Definitions

Reserve	A virgin or accessed part of a reserve base which could be economically extracted or produced at the time of determination considering environmental, legal and technologic constraints. The term "reserve" does not signify that extraction facilities are in place and operative. "Reserves" include only recoverable coal; thus, terms such as "extractable reserves" and "recoverable reserves" are redundant and are not a part of this classification system.
Resource	A naturally occurring virgin or accessed concentration or deposit of coal in the earth's crust in such form and amount that economic extraction is currently or may become feasible.
Identified Coal Resources	Resources whose location, rank, quality, and quantity are known or estimated from specific geologic evidence. Identified coal resources include economic, marginally economic, and subeconomic components. To reflect varying degrees of geologic certainty, these economic subdivisions can be subdivided into demonstrated, measured, indicated, and inferred.
Demonstrated Resource	A term for the sum of accessed and virgin coal classified as measured and indicated resources. These resources are divisible on the basis of economics and criteria of depth, thickness, rank, and distance from points of measurement into reserve base, reserves, marginal reserves, and subeconomic resources.

(Continued)

TABLE 1
(Continued)

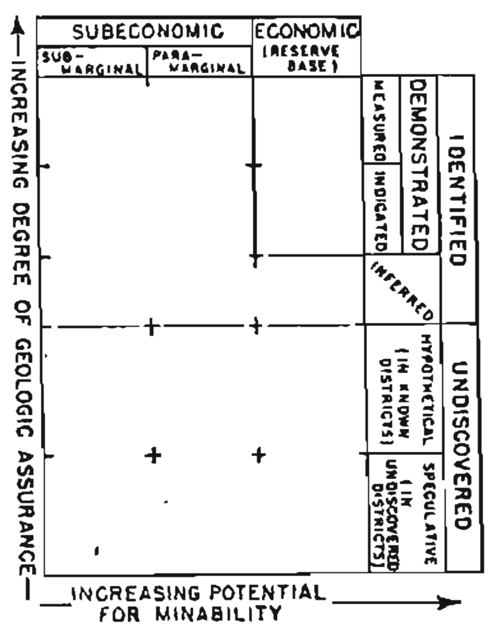
<u>Measured Resource</u>	A category of accessed and virgin demonstrated coal resources having a high degree of geologic assurance. Estimates of quantity are computed partly from dimensions revealed in outcrops, trenches, workings, and drill holes and partly by projection of data not exceeding a specified distance. The sites for inspection, sampling and well-defined measurement are so closely spaced and the geologic character is so well defined that the size, shape, and depth of resource bodies are well established. However, a single measurement can be used to classify nearby coal as measured.
<u>Indicated Resource</u>	A category of virgin demonstrated resources having a moderate degree of geologic assurance. Estimates of quantity, thickness, and extent are computed by projection of thickness, sample, and geologic data from nearby outcrops, trenches, workings, and drill holes for a specified distance beyond coal classed as measured. The assurance, although lower than that for measured resources, is high enough to assume continuity between points of observation. There are no sample, measurement, or inspection sites in areas of indicated coal.
<u>Inferred Resource</u>	A category of virgin identifed bodies of coal having a low degree of geologic assurance. Estimates of quantity, quality, thickness and extent are based on inferred continuity beyond measured and indicated resources for which there is geologic evidence. Estimates are computed by projection of thickness, sample, and geologic data from distant outcrops, trenches, workings, and drill holes for a specified distance beyond coal classed as indicated. There are no sample, measurement, or inspection sites in areas of inferred coal.

(Continued)

TABLE 1
(Continued)

<u>Hypothetical Resources</u>

Undiscovered coal resources that are similar to known coal deposits and that may be reasonably expected to exist in the same coal field or region under analogous geologic conditions. In general, hypothetical resources are in the central parts of broad areas of coal fields where points of sampling, measurement, and inspection are absent and evidence for thickness and existence is from distant outcrops, mine workings, drill holes, and wells. If exploration by geologic mapping, geophysical surveying, and drilling confirms their existence and reveals enough information about their quality, quantity, and rank, they will be reclassified as identified resources.



Coal resource classification system (U. S. Bureau of Mines and U. S. Geological Survey, 1976) beneath the Quaternary loess cover. A density of 80 lbs./ft3 was assumed for lignite from standard tables. The results of these calculations are shown in Table 2. The total demonstrated resource currently defined for the Chicago Creek deposit is 3.4 million short tons.

Inferred resources from reasonable extensions off the north end of the deposit and the probable continuity of coal beds in Segments IV and V could add an additional 1 million tons. Magnetometer surveys performed during surface geophysics (Appendix A) suggest this to be the case. Further surveys to the north may verify these and additional inferred resources.

Hypothetical resources in the Chicago Creek area could be very substantial. The continuation of the coal bed south of the probable fault is likely considering other known occurrences on strike to the south. The north extent of the bed is also open at this time. In addition, it is quite possible that still other beds lay undiscovered. Hypothetical reserves could be easily 10-20 times the size of the existing demonstrated resource.

TABLE 2

Coal Resource Estimation

SEGMENT	HOLE NO.	MINEABLE STRIKE LENGTH (FT)	AVE. BED THICKNESS (FT)	DENSITY FACTOR	PREVIOUSLY MINED (TONS)	MINING DEPTH (FT)	DIP LENGTH (FT)	DEMONSTRATED COAL RESOURCE (SHORT TONS)
I	1-82 4-82	700	88	$\frac{80\ LB/FT^3}{2000\ LB/TON}$	100,000	100 200 300	141 283 424	347,420 697,310 1,044,740
II	6-82 5-83 6-83 11-82	1,100	20	"	NONE	100 200 300	141 283 424	124,080 249,040 373,120
III	10-82 13-82 1,2,3 -83	NONE	NONE	"	NONE			
IV	7-82 8-82	1,200	28	"	NONE	100 200 300	141 283 424	189,500 380,350 569,850
V A	7-83 8-83	1,000	39	"	NONE	100 200 300	141 283 424	219,960 441,480 661,440
V B	9-83 thru 14-83	2,300	20	"	NONE	100 200 300	141 283 424	259,440 520,720 780,160
TOTAL ALL SEGMENTS		6,300	N/A	N/A	N/A	100 200 300	141 283 424	1,140,000 2,288,900 3,429,000

* U.S.G.S. Definition, 1980; Includes both Measured and Indicated Resources

Preliminary Mine Plan and Feasibility

Preliminary mine planning must consider not only the size and character of the deposit, but also potential markets, their location, and the price that can be commanded there. The previous discussions have defined the character and size of the Chicago Creek deposit, but nothing about demand for this coal. Quite a bit of study has been done on this subject in the last few years, and the results of those studies are summarized in the following discussion:

Market Demand

It is perhaps obvious that a lignitic coal such as that found at Chicago Creek will not be competitive if transported outside of the local communities, so the principal concerns will be: 1) Is there truly a local market? 2) What other alternative energy sources can Kotzebue and nearby communities rely on, and at what cost? 3) What is the total energy demand and how much coal might be needed to displace it? Answers to these questions have been attempted by at least three reports over the past four years, all funded by Alaska Power Authority (see R. W. Retherford & Associates, 1980; Dames and Moore, Resource Associates of Alaska, 1980; and Arctic Slope Technical Services and others, 1982). The latest report, by Arctic Slope Technical Services and its associates (ASTS), is the most current and also summarizes parts of the other two reports.

In brief, the report compared several methods of providing electricity and heat to Kotzebue for the next 20 years. Important findings regarding this discussion were:

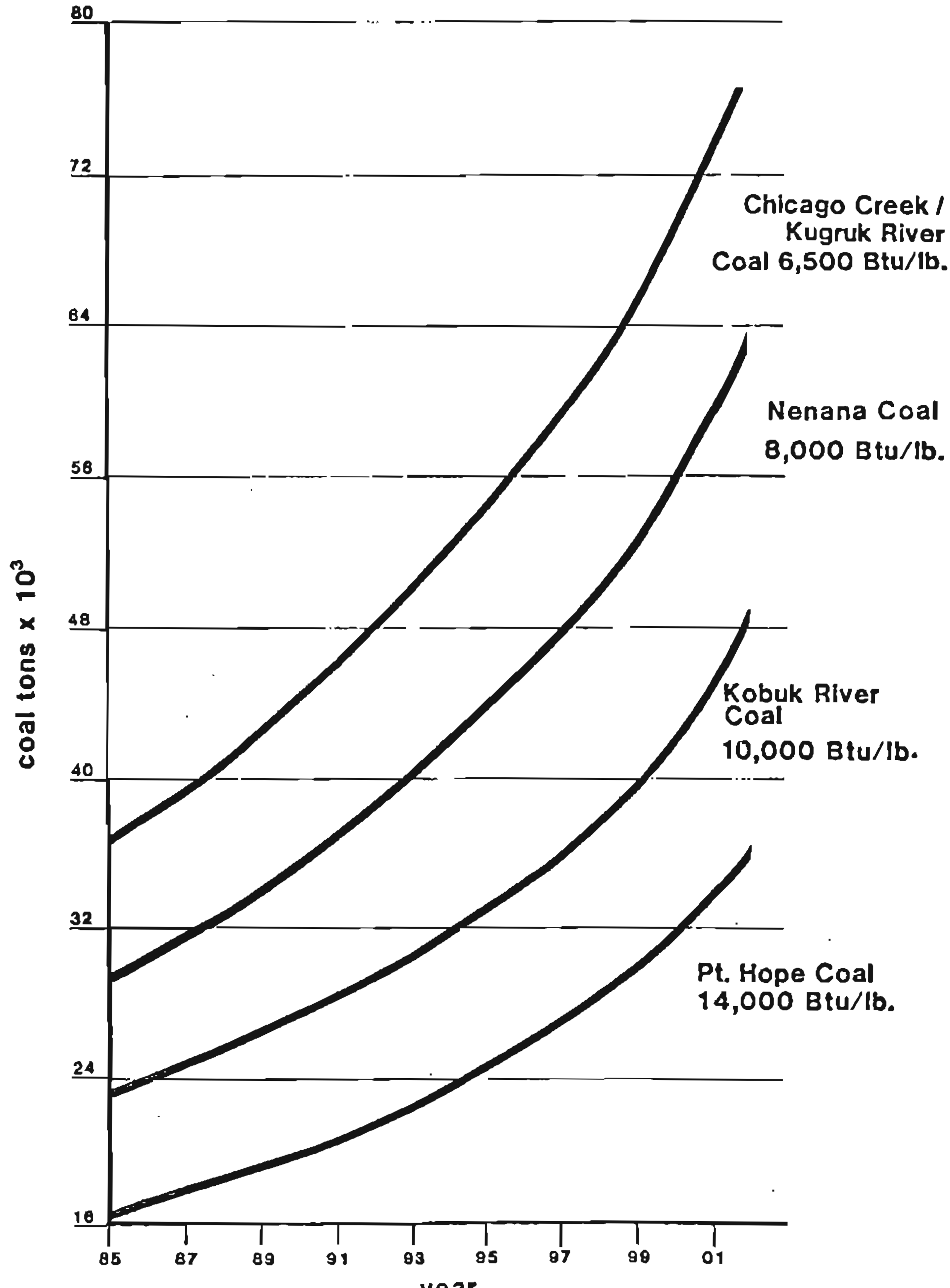
> 1) Coal-fired cogeneration (both electric power and space heating from the waste heat) was found to be economically competitive against diesel, hydropower, geothermal and wind. Furthermore, any coal delivered to Kotzebue costing $6/million Btu's or less would probably become the least expensive fuel for the near future.
>
> 2) Total energy demand for Kotzebue is forecast to increase about 5% per annum so that about 80,000 tons of Chicago Creek-type coal will be required by 1995. Table 3, from the ASTS, 1982 report, shows demand for various coals based on supplying district heating only. Electrical demand would add 25,000 to 30,000 tons/year. Increases in demand from there on could require as much as 2.8 million tons over the 25-year period following 1990 (Table 4).
>
> 3) Coals from four separate areas were compared to see which appeared to be the most economic: Point Hope, Kobuk River, Chicago Creek, and Nenana coals. Their analyses showed the high BTU coal of the Cape Beaufort area to be the cheapest product. This last finding, however, is based on several assumptions which are uncertain, such as the cost of transportation of Point Hope coal.

In general, then, a market does seem to be present, and it would require enough annual production of coal to make a mining operation generally feasible. The price of the delivered Chicago Creek coal

TABLE 3

COAL REQUIREMENTS

COAL FIRED COGENERATION (ALTERNATIVE B) **



* From Arctic Slope Technical Services Report, 1982.

** Alternative B required coal for a district heating system only.

TABLE 4

Potential Demand for Coal Mined Over 25-Year Period*

Year No.	Date	Tons (X 1000)
1	1990	65,000
2	1991	65,000
3	1992	65,000
4	1993	65,000
5	1994	78,000
6	1995	78,000
7	1996	78,000
8	1997	78,000
9	1998	94,000
10	1999	94,000
11	2000	94,000
12	2001	94,000
13	2002	113,000
14	2003	113,000
15	2004	113,000
16	2005	113,000
17	2006	136,000
18	2007	136,000
19	2008	136,000
20	2009	136,000
21	2010	163,000
22	2011	163,000
23	2012	163,000
24	2013	163,000
25	2014	196,000
	TOTAL TONS	2,792,000

Average Tons/Year = 111,000

* Total energy demand is estimated to increase 5-6 percent per annum by Arctic Slope Technical Services, and others, 1982. Assumes coal-fired cogeneration displaces all of this demand.

would have to be somewhere near $85/ton ($6/M Btu's) to be competitive with other coals. A complete feasibility study must be done before a delivered cost of Chicago Creek coal can be made. Considerations will include not only the various mining and transporting methods, but also land status, environmental impact, and owner-developer financing strategy.

Mine Planning

The following discussion will be limited to possible mining and transporting methods. Several techniques can be used for actually removing the coal; all studies to date have assumed surface or open-pit mining will be the most economic. This report makes the same assumption; however, a more rigorous review of possible underground mining methods in steeply dipping frozen seams should be carried out. For instance, underground hydraulic methods are being employed with success under certain conditions, although excess water in permafrost could obviously cause problems. The French are using longwall techniques in very steeply dipping seams today, and the cost of this mining technique should be compared. The Norwegians have developed underground coal mines in permafrost terrains, and the frozen ground has proven to have some real advantages such as more competent walls and backs and very low dust problems. Their methods and costs should be reviewed. The Russians probably have the most experience in similar conditions, and there are a number of Russian publications that should be reviewed. Some of these methods could prove more economic than open-pit, particularly if depths over 300 feet are to be considered.

A general mine plan for an open-pit style of operation shows a general layout of the pit, housing and maintenance facilities, and transportation network (Figure 4). Access to the site and haul road to the coast is proposed to follow the drainage of Willow Creek down to Willow Bay, a total distance of about nine miles. This route is most direct to the coast, crosses only two small tributaries and would follow a fairly gentle gradient all the way.

Land status was not determined for this study; and, although environmental factors were considered, environmental studies have not been made. It is assumed that a 4-foot road bed of gravel laid down on a porous fabric lying directly on the tundra would provide a firm base for light summer traffic and heavy usage during the frozen months. This route would also parallel additional inferred and hypothetical resources north of the pit area. A material site for gravel would be sought near the mouth of Willow Creek.

During early development, a temporary camp would be established on Willow Bay. The road and gravel pier could be constructed at the

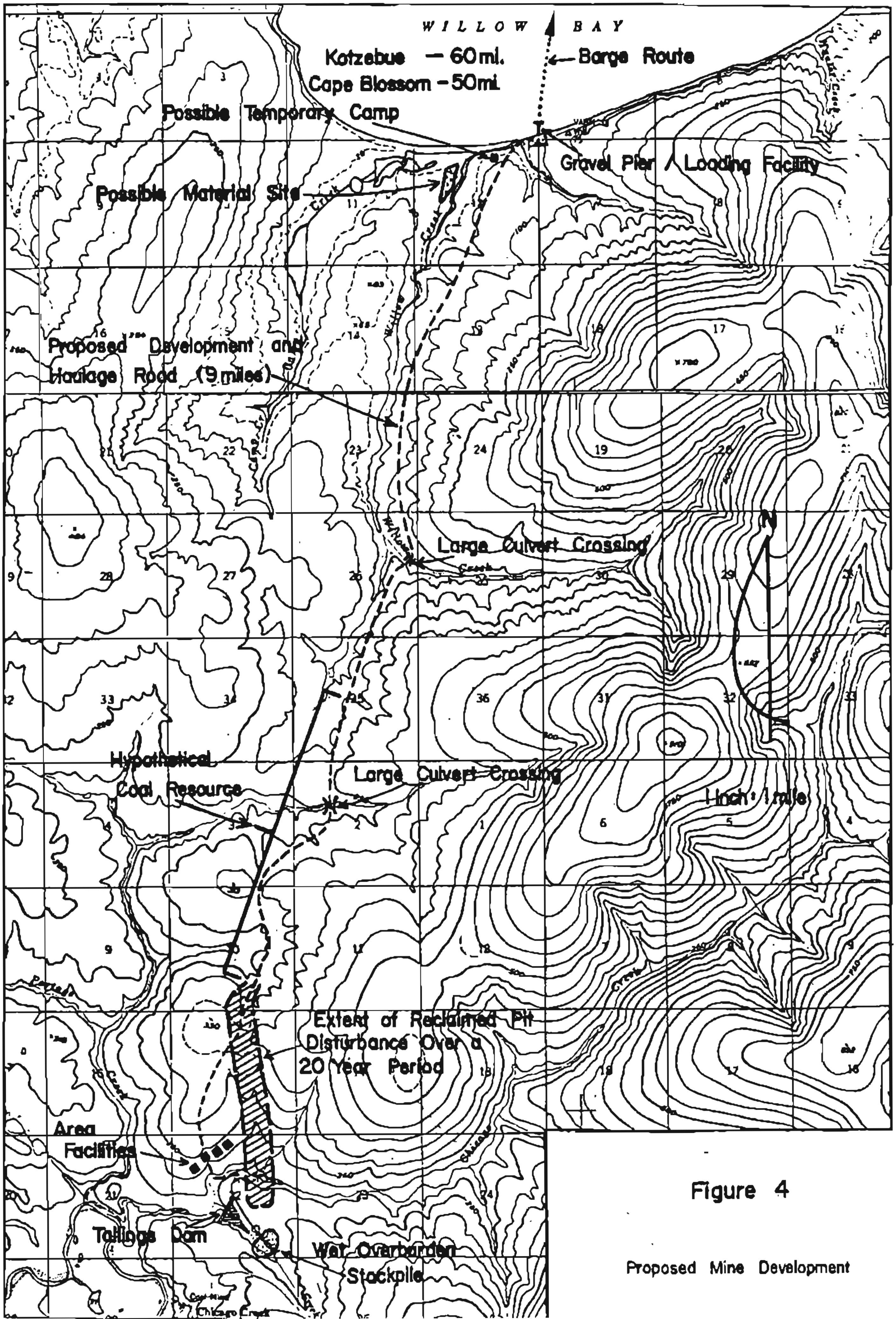


Figure 4

Proposed Mine Development

same time. Once the road was completed, permanent facilities could be established, and stripping of the overburden at the south end of the pit would begin. In conjunction with selective stripping, a small tailings dam could be established at the mouth of Contact Creek so that melting ice-rich materials could be stored without the danger of runaway erosion and mudflows.

Eventually, as the development stage is completed, coal could be moved to Willow Bay by truck during winter months. Barges of the 9200 DWT category would then move an entire year's coal production during a single operation. The coal would be stockpiled near the power and heating plant where waste heat could be used to partially dry the coal immediately prior to burning.

The open-pit mining operation itself would be composed of a 25-man crew operating cats, loaders, 20- and 35-ton trucks, and a close-spaced drill and blast program. Initially, the ice-rich loess blanket would be stripped back past the future pit edge. The material removed would be stored behind the tailings dam. The exposed face of the loess (10-30 feet in height) would be insulated by stacking relatively dry waste rock from the pit against it.

The pit's eastern wall would follow the dipping coal bed sloping at approximately 45 degrees. The western highwall would have an overall slope of from 35-40 degrees and incorporate a series of terraces suitable for climbing out of the pit or simply returning to the open, southern end of the pit. The pit would be designed to maintain a 50-foot working width at full depth and maintain grades at no greater than 10-12 percent. In this regard, it could prove efficient to use a conveyor system, the cost/ton-vertical foot being about one-half that of trucks and with the great advantage of ascending steep slopes.

In order to determine stripping ratios, cross-sections of the proposed pit were plotted, areas measured, and volumes calculated for certain segments (Table 5). The southern end of the pit, with thicker beds and less cover, is the most attractive target for strip mining with an average ratio of about 5.5:1. A diversion of Chicago Creek would be necessary at the south end.

Costs of mining the Chicago Creek coals have been estimated in previous studies. The estimates made in 1980 by R. W. Retherford & Associates were about $65/ton delivered to Kotzebue. Estimates made by Arctic Slope Technical Services and associated contractors in 1982 ranged from $83 to $103 per ton, depending on what was included in

TABLE 5

Summary of Stripping Ratios

Segments	Length Mined	Mining Depth	Stripping Ratio (Yd3/Ton)
I, II, III	2,400 Ft.	100 Ft.	4.8 : 1
		200 Ft.	5.6 : 1
		300 Ft.	6.8 : 1
IV, VA, VB	5,700 Ft.	100 Ft.	8.9 : 1
		200 Ft.	11.0 : 1
		300 Ft.	14.0 : 1

development costs. Using the mine plan and transportation system just discussed, a cost estimation was initiated for this report; like the previous estimates, it was necessary to make several assumptions. Without going into the details of these assumptions, it became apparent that the confidence of any cost/ton number generated would be low (perhaps off by as much as 50%). While the actual dollar/ton price generated was around $90, it is important to stress the vulnerability of all the numbers advanced to date. The best that can be said is that it is very possible Chicago Creek could be mined economically and that more work will need to be done to raise the degree of that confidence. Much of the field site work has now been accomplished, and the analysis of Kotzebue market demand is complete and current. A more detailed mine engineering analysis is needed.

Conclusions

With the additional work, the Chicago Creek coal resource has a good chance of becoming a reserve in the not too distant future. The quality and quantity of the resource have been defined, the market for the coal has been studied carefully, and there appear to be no overwhelming factors against its development. Chicago Creek will have to be weighed against other Alaskan coal sources and then moved into a true mine feasibility study.

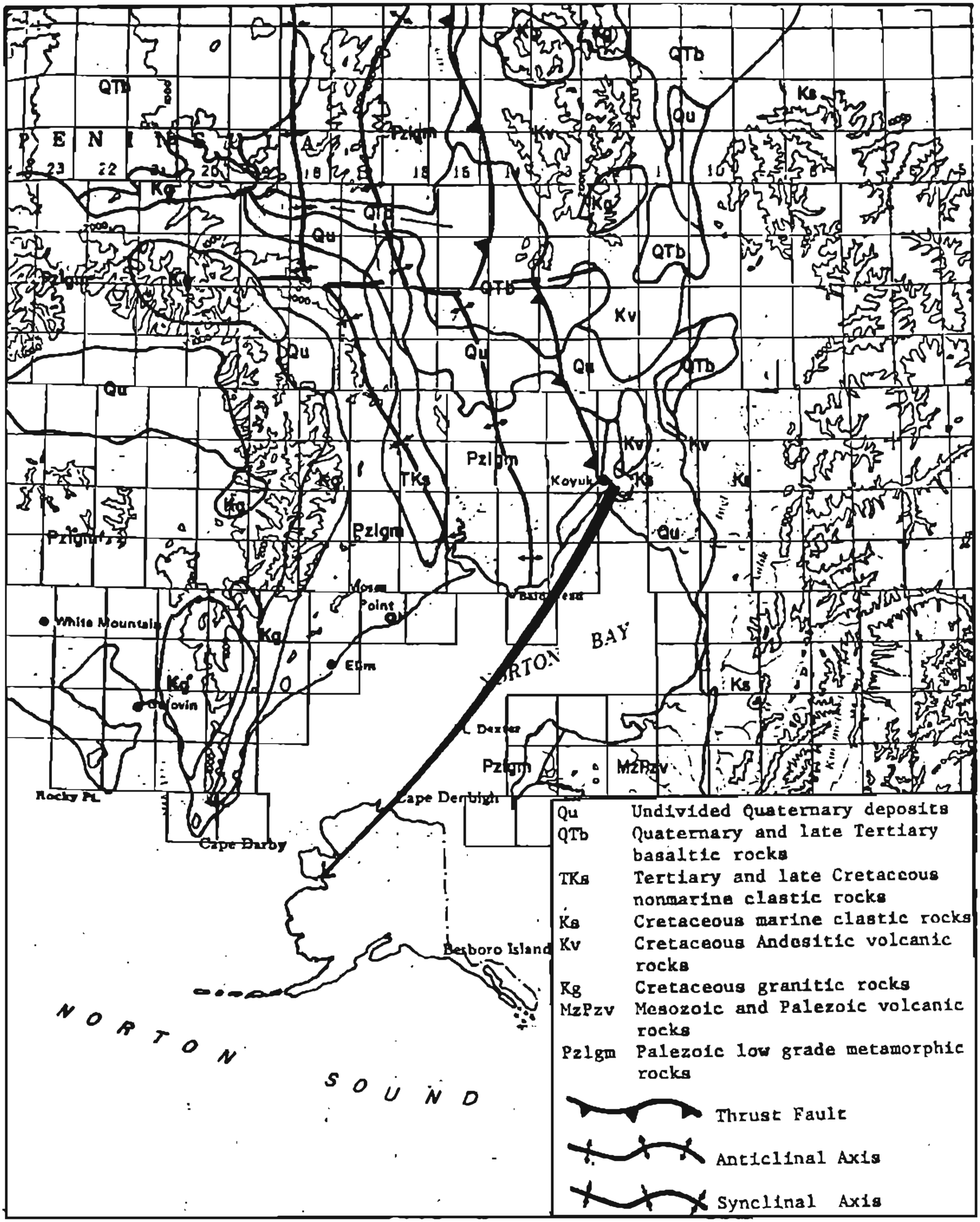
B. Koyuk

Introduction

The Koyuk Coal Exploration Project, initiated on September 1, 1983, consisted of a surface mapping effort and a drilling program. Surface geologic reconnaissance mapping was done within and outside of the project area, approximately 230 acres, located near the mouth of the Koyuk River. The drilling program consisted of 12 rotary drill holes and one core hole, drilled to a cumulative total of 1,442 feet. The project was completed on September 6, 1983.

Location

The Koyuk project area is near the mouth of the Koyuk River on the northern end of Norton Bay. The position of the Koyuk area relative to the other project areas and major geographical features is shown in Figure 1. The project area is about one mile east of the town of Koyuk; and is bordered on the south by the Koyuk River and to the east by Coal Creek. A more detailed regional view of the project area geography is shown in Figure 5.



Base map topography adapted from A.E.D.C. 1:1,000,000

Regional Geology and Index Map - Koyuk, from Hudson 1977, Patton 1973, Till et al 1983

Figure 5

Access

Personnel and camp equipment were transported to and from Koyuk on local commercial air services. The drilling equipment was barged from Nome up the Koyuk River to a beach adjacent to the project area. Nodwells and three wheel all-terrain cycles provided access to the project area and to the town of Koyuk.

History

The Koyuk coal occurrence was first prospected sometime before 1909 (Smith and Eakin, 1911). It was during this time that prospect shafts, the sites of which are still visible, were excavated. In 1909 P. S. Smith and H. M. Eakin camped near the Koyuk coal occurrence; their report (1911) notes that:

> "Several openings have been made near the mouth of the Koyuk on the western side close to camp B17. Unfortunately the shafts were not in a condition to be examined, and the only information gained was from a study of material on the dump, as there are no exposures of the coal bearing rocks in the neighborhood. Although lignitic material was found at this place, several years of desultory prospecting failed to disclose a workable bed. The shafts show a series of sandstones and clays which have weathered badly on the dump and appear to be much less consolidated than the average sandstones near Nulato. It is understood that during 1909 the company formerly interested in this claim abandoned the enterprise. In this same region coal float has been found on Coal Creek and claims have been recorded,

but none of them was being prospected in 1909. Probably little of value was found as the series is without doubt similar to that near camp B17."

The amount of coal produced is not known. However, based on the size of the shafts and dumps it is unlikely that it was a significant amount. Stevens (1982) cited an estimated past production of 50 tons of coal.

Local people have occasionally used coal float picked up off the beach for heating. Coal fragments are found along both the Koyuk River and Coal Creek. Townspeople also recall that over the years barges laying in the mouth of the Koyuk River have dragged up coal when lifting anchors. Smith and Eakin (1911) noted the presence of this coal float but state that no beds that warrant investigation had been discovered.

Previous Investigations

A thorough research and reading of previous investigations provided a wealth of information detailing the geology of both the Koyuk and Unalakleet areas. Many of the finest turn of the century U. S. Geological Survey geologists, including A. H. Brooks, P. S. Smith, H. M. Eakin, and G. L. Harrington, described these coal occurrences. There are, however, some contradictory statements concerning the Koyuk coal found in these early publications; this should not be surprising given the nature of the times--poor communications, lengthy travel times, and arduous field conditions. The contradictions have been exacerbated by subsequent literature research that either failed to examine all the publications available or misinterpreted the statements made in the reports detailing these early investigations.

Smith and Eakin (1911) state that, " there are no exposures of coal bearing rocks in the neighborhood." In contradiction to their detailed report, which is extensively quoted above (see History); Harrington (1919) writes in a report that has been frequently quoted in recent literature surveys that: "Coal . . . is found near the mouth of the Koyuk, just about at sea level, where one 4 foot seam is said to be exposed. Near by a 2 foot seam, and several seams of a few inches in width also occur." Harrington concludes by acknowledging the second hand nature of his information: "The locality on the Koyuk was not visited, but it is said to be at or near tidewater, and some difficulty might be had at times in mining on account of flooding."

J. T. Cass (1959) on the basis of previous work and air photo interpretation mapped a wedge of Cretaceous sediments 2-3 miles north of the Koyuk project area near the headwaters of Coal Creek. Cass does not identify any particular coal occurrences found in the Tertiary sediments. The 1983 project area was mapped originally by Cass as Quaternary alluvium. More recent work by Patton (1973) and Hudson (1977) has placed the closest extensive exposures of Cretaceous sediments at least 20 miles north and east of the project area.

As part of the 1982 Norton Sound Area Coal Exploration Program, Stevens Exploration Management and others (1982) conducted a reconnaissance examination of the Koyuk coal occurrence. An area of 200 feet x 100 feet located along the Koyuk River beach was tested with an auger type drill. A seam of coal measuring 1 to 4 feet and continuous for up to 50 feet was intercepted. The thickest part of the seam was intercepted in the center of the drilling pattern; and the seam abruptly diminished in thickness away from the 4 foot lens.

Regional Geology

The coal bearing section at Koyuk is part of a thick, structurally complex, Cretaceous to Tertiary (100-50 my) sedimentary sequence that is preserved on the Seward Peninsula as erosional remnants in tectonically downwarped basins (Figure 5). This sedimentary sequence, which hosts nearly all the Norton Sound area coal occurrences, consists of terrigenous and volcanogenic greywacke, mudstone, sandstone, conglomerate, and coal (TKs). The rocks occur locally as poorly indurated silt, sand, and clay. These rocks, which in the past have been called the Shaktolik group (a term now abandoned), are now considered to be equivalent to the Kaltag and Nulato Formations and the Ungalik Conglomerate (Patton, 1973).

In the Koyuk area, the sequence is found west of the Koyuk River as a series of thin bands and wedges separated by thick alluvial deposits of Quaternary age (Qu) and east of the Koyuk River as a thick and areally extensive sheet. The sequence is thought to continue upriver for some 30 miles (Harrington, 1919; Hudson, 1977) and may also underlie the offshore Norton basin (Scholl and Hopkins, 1969).

The coal bearing section at Koyuk is bounded to the west by Carboniferous or older metamorphosed sedimentary rocks (Pzlgm). To the north, these and other volcanic rocks of unknown age form rolling hills that rise above the Norton basin. East of the Koyuk coal occurrence, a thick blanket of Quaternary marine and alluvial deposits forms the Koyuk River flood plain (Cass, 1959; Hudson, 1977).

Project Area Geology

Surface Geology

The Koyuk project area (Plate 5) is located on a low-relief bench some 20-30 feet above high tide line. Holocene and Quaternary deposits outcrop along the river and stream cut margins of this bench. The Quaternary exposures are predominantly dark colored silt, sand, and clay rich in decaying peat. The south bank of the Koyuk River, opposite the project area, is being actively undercut and abundant Quaternary fossils, including mammoth teeth and tusks are washing out. The exposures are interpreted to be flood plain, terrace, and beach deposits. Infrequent horizons of shell fragments indicate some periods of marine encroachment.

In agreement with the turn of the century field work of Smith and Eakin no exposures of coal bearing rocks were found within or immediately adjacent to the project area. The prospect shafts are completely filled and the dumps are only barely recognizable as tundra covered mounds. Excavation of these mounds yielded a mixture of badly weathered, unconsolidated sandy silt, clay, and very rare coal chips.

Information provided by Koyuk resident Vernon Swanson suggested that an exposure of coal bearing strata occurred some distance north of the project area along Coal Creek. Two reconnaissance traverses were made along Coal Creek to a distance of 2-3 miles north of the project area. One exposure of unconsolidated sands and silts was tentatively identified as part of the coal-bearing Tertiary section, but no coal seams were found.

Subsurface Geology

The subsurface geology was evaluated by examining the geophysical logs (Appendix B) and lithic cuttings (Appendix C) from 12 rotary bore holes and one core hole drilled to a cumulative total of 1,442 feet. The location of these drill holes is shown on Plate 5. The drilling effort provided a detailed stratigraphic picture of the project area. The drilling pattern was planned so that:

1) The section in the vicinity of the abandoned shafts and the 1982 drilling effort was thoroughly evaluated.

2) The project area coal potential was as completely tested as possible.

3) The areas with obvious mining and/or environmental problems (i.e., tidewater and anadromous fish bearing water) were not emphasized at the expense of areas within the project area which would be more amenable to mining.

Stratigraphy

The stratigraphic section drilled at Koyuk is generalized in an illustration shown on Plate 5. The section at Koyuk includes a 25 to 30 foot thick Holocene and Quaternary unit unconformably overlying an unknown thickness of Cretaceous to Tertiary terrigenous sediments. The Holocene and Quaternary unit described above is characteristically composed of silty clay and sand rich in organic components. Ice, occurring as accretionary wedges and as interstitial filling of void space within the Quaternary sediments, is common and may be as much as 70 per cent of the total volume for any 10 foot drill hole interval.

The contact of the Quaternary and the older coal-bearing sediments is an angular unconformity. The lowest Quaternary bed contains light green silty sand and clays with abundant shell fragments. The shell fragments, primarily 1-4 inch diameter pelecypods and rare smaller gastropods, are thought to be marine in nature. This contact is inferred to represent a marine transgressive event.

Samples of the Cretaceous to Tertiary section at Koyuk revealed a section rich in gray colored silts with rare thin coal lenses. The section was well represented by core hole DH-K13-83 which yielded thin

(1/2-6 inch) low angle cross bedded, unconsolidated silts, and sands with frequent thin laminations of silty clay. Lignitic fragments and rare coal chips occurred in horizons distributed throughout the silty sediments.

Thin, drill resistant carbonate horizons were common throughout the section. It is not known whether these horizons are a primary deposition feature or a post-depositional groundwater phenomenon.

The few coal horizons encountered, appeared to be lenticular masses occurring on discontinuous horizons rather than continuous seams. The Koyuk coal contains a significant amount of vitrain and can be classified as subbituminous. Samples of the coal were taken from DH-K12-83 and DH-K13-83; analyses of these samples will be published at a later date. The sample from DH-13-83 was a core from a six inch bed of subbituminous coal that was deposited on and overlain by 1 to 2 inch thick silty clay beds.

Structure

The attitude of the Koyuk Tertiary section was determined by triple point analysis of horizons judged to be similar in lithologic character and density log response. Correlation was only possible between closely spaced drill holes. The section apparently strikes

N 70 degrees E to N 85 degrees E and dips 10 to 20 degrees to the south. Examination of core from hole DH-K13-83 showed beds to be dipping at roughly 15 degrees.

Although several major lineaments can be seen striking across the hills toward the Koyuk Project area, abundant ground cover obscures any surface expression of faults within the project area. No fault zones were recognized in the subsurface.

Depositional Environment

The environment of deposition of the Cretaceous to Tertiary section, at Koyuk, is inferred to represent the marginal marine distributary system of a delta environment. The discontinuous coal lenses probably represent small lenticular sites behind levees that allowed for the protected deposition of organics. These ephemeral coal depositional sites were terminated by anastomosing channels and frequent over bank flooding. The inference that the Koyuk coal bearing rocks represent a distributary section of a delta suggests that significant coal deposition is unlikely anywhere within this environmental facies. It is, however,possible that environments adjacent to the distributary system and in general more marginal to the active delta may have significant coal potential.

Coal Resources

The coal horizons encountered at Koyuk were thin and discontinuous. Also, the Cretaceous to Tertiary section hosting the rare coal horizons within the project area was found to be covered by a thick (>25 feet) blanket of Quaternary overburden. The lithologic and geophysical logs show that the largest coal seams identified, with the single exception of one intercept 3.5 feet thick found at a depth of 57 feet in DH--K5--83, were less than 1.5 feet thick. The seam in DH--K5--83 was not located in any adjacent drill holes and appears to be unrelated to the coal bearing horizons associated with the old prospect shafts. Drill holes DH-K1-83, DH-K2-83, DH-K12-83, and DH-K13-83 were drilled within a 200 foot radius of the abandoned prospect shafts and within 400 feet of the 1982 drill sites. The largest coal seam identified in this area was approximately 1 foot thick and occurred at a depth of 35 feet.

Conclusions and Recommendations

It is very unlikely that any economically workable coal seams exist within the study area. The Cretaceous to Tertiary section underlying the project area is an unfavorable environmental setting for economic coal deposition. Despite local unconfirmed reports of coal in areas immediately adjacent to the project area, it is improbable that any workable coal seams will be found in nearby sediments with a depositional setting similar to the section evaluated. The origin of the abundant coal float seen on beaches adjacent to the project area is problematic. Although it is possible that the coal float is eroded from the meager local section; it is speculated that the coal comes from beds which have no connection to the Koyuk section and are from potentially economic source(s) some distance upriver.

A coal based energy self-sufficient future for the community of Koyuk may still be possible. As the drilling results and abundant coal float attests, there is coal bearing strata in the Koyuk Basin. All that remains to be accomplished is for a vigorous prospecting program to identify a workable seam of coal. Therefore, it is recommended that the Koyuk basin (upriver from the project area) be explored and evaluated using paleoenvironmental techniques (i.e., paleo-current and depositional setting analysis). A program of this sort would specifically target lithologies representing environments hospitable to the deposition of economic coal seams. Previous workers including Harrington (1919) and Patton (1973) have already identified some potential coal bearing Cretaceous and Tertiary sections in the Koyuk basin. One of these sections is poorly exposed in the vicinity of Dime Landing. Local residents may be of assistance in locating other such occurrences.

C. Unalakleet

Introduction

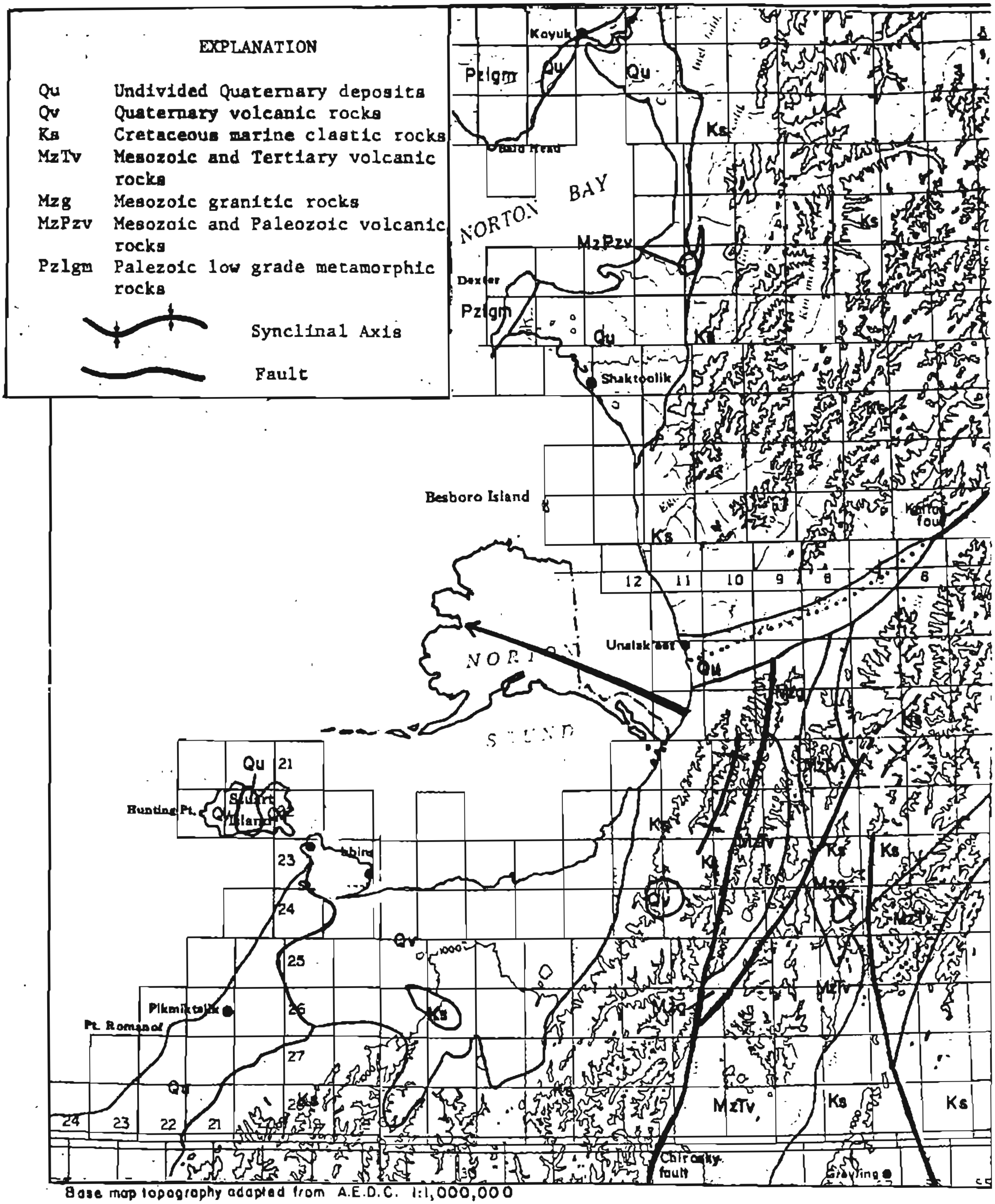
The Unalakleet Coal Exploration Program was started on September 8, 1983. The project consisted of a surface mapping effort and a drilling program. Surface reconnaissance was done within and outside of the project area. The drilling program consisted of 12 rotary drill holes. The 12 holes were drilled to a cumulative total of 1,823 feet. The program was completed on September 16, 1983.

Location

The location of the Unalakleet coal occurrence is shown in Figure 1. The outcrops of coal are located 8 miles south of the town of Unalakleet, across the Unalakleet River, and at the mouth of Coal Mine Creek. Regional geography is shown in Figure 6. Detailed local geography is presented on Plate 6.

Access

Personnel and camp equipment were transported in and out of Unalakleet on local commercial air services. The drilling equipment was barged from Koyuk across Norton Sound to a beach adjacent to the



Regional Geology and Index Map - Unalakleet, from Cass 1954, Eberlien 1977, Patton 1973

Figure 6

project area. Personnel and supplies were transported to and from the town of Unalakleet via local dorries. Nodwells and three wheel all-terrain cycles provided access to the project area and along the beach to the Unalakleet River.

History

The coal outcrops along the beach near Coal Mine Creek have been repeatedly mined. Cathcart (1920) reports that 300 tons of weathered coal were sent to St. Michael and Nome, for use in steamships, sometime in 1918. The only structures remaining at the site of the coal occurrence is a rustic fish camp. There is no evidence of the timber supported adit reported by Cathcart. Local residents reported in informal conversations (1983) that coal from the beach was used for heat in residences and church buildings until the early 1960's.

Previous Investigations

J. T. Cass (1959) mapped the Unalakleet project area as Shaktolik Group of Cretaceous age sediments. The mapping done by Cass was the first comprehensive geologic information published on the Unalakleet coast. His efforts, however, were built upon the work of several individuals who mapped adjacent areas, including: Smith and Eakin, 1911; Harrington, 1918; and Patton and Bickel, 1956.

W. W. Patton (1973) in a reconnaissance of the northern Yukon-Koyukuk structural province mapped the Unalakleet project area and specifically measured and dated the coal-bearing section at Coal Mine Creek. Patton wrote that, "Clays containing lignitic coal were discovered in a badly slumped beach bluff 10 miles south of Unalakleet on the shore of Norton Sound. Samples of the coal yielded an abundant pollen flora of early Tertiary age (E. B. Leopold, written commun., 1966)." Patton identifies the Cretaceous sediments (mapped by Cass (1959) as Upper Cretaceous nearshore and nonmarine sandstone, mudstone, and coal (Ks--Figure 6).

As part of the 1982 Norton Sound Area Coal Exploration Program, Stevens Exploration Management Corporation (1983) conducted a brief reconnaissance examination of the Unalakleet coal occurrence. The findings of the 1982 effort included a description of the coal as being found in "flat-lying Early Tertiary shales". The 1983 Northwest Coal RFP contained a map done by Eakins and Stevens in 1982 that showed the placement of coal seams along the shoreline.

Regional Geology

The east coast of Norton Sound, in the vicinity of Unalakleet, is characterized by a thick and areally extensive package of terrigenous and volcanogenic Cretaceous sediments (Ks--Figure 6). This assemblage of Cretaceous sedimentary rocks, which has in the past been called the Shaktolik group (a term now abandoned), is now considered to be equivalent to the Kaltag and Nulato Formations and the Ungalik Conglomerate (Patton, 1973). These sedimentary rocks, mostly greywacke, mudstone, sandstone, and coal were deposited in a short interval of mid--Cretaceous time and cover much of the Norton basin and probably underlie a large portion of Norton Sound (Scholl and Hopkins, 1969).

The Cretaceous sediments in the Unalakleet region are bordered to the south by Quaternary basalt flows (Qv--Figure 6). Twenty miles to the east of the Unalakleet coal occurrence on the divide between the Yukon River and Norton Sound, Mesozoics granitic and andesitic rocks (Mzg, MzTv--Figure 6) are juxtaposed against Cretaceous sediments by the Chirosky Fault. The Kaltag Fault cuts close to the northern end of the project area. The fault is a major feature which cuts and deforms the Cretaceous strata (Patton, 1973).

Project Area Geology

Surface Geology

The Unalakleet project area (Plate #6) is located on a deeply incised, badly slumped beach bluff. The Quaternary and Tertiary to Cretaceous section is well exposed on the cliff faces of the beach bluff and on the beach above and below tideline. Coal seams are exposed at several locations along the beach. Inland of the beach and bluff, thick vegetation covers the section except for rare exposures of Quaternary deposits in the deeply incised but brushy streams. At the extreme eastern edge of the project area rolling hills rise above the coastal plain and outcrops of Cretaceous sedimentary rocks are common.

Geologic mapping along the beach is complicated by the presence of large slump blocks (Plate 6). This mass wasting phenomenon is caused by the partial thawing of permafrost along a steep bluff face and the subsequent slope failure. The arcuate fault at the failure point at the top of the block can be 15 feet deep and 40 feet wide. The net result of this slope failure is a beachward rotation of the block (sketch on Plate 6), which dramatically effects the appearance of the sedimentary attitudes.

Age of Section

The Unalakleet coal bearing section has been dated on the basis of pollen content as early Tertiary (Patton, 1973). The relationship of the coals to the more indurated sandstones and shales found down-section along the beach and to the similar looking Cretaceous sandstones and shales which form the eastern hills is unclear. The coal bearing clays seem to be conformable with the underlying indurated sandstones and shales. It is speculated that deposition was continuous throughout early Tertiary and late Cretaceous time.

Subsurface Geology

The subsurface geology was evaluated by examining the lithic geophysical logs (Appendix B) and lithic cuttings (Appendix C) from 12 rotary bore holes. The holes were drilled to a cumulative total of 1,8[illegible] feet. The location of these drill holes is shown on Plate 6. The drilling effort did not add substantially to the stratigraphic detail assembled from the surface mapping. The drilling pattern was planned so that:

1) The project area coal potential was as completely tested as possible for this project.

2) The area adjacent to the coal beds on Coal Mine Creek was specifically tested.

3) The areas with obvious mining and/or environmental problems (i.e., tidewater and slump blocks) were not emphasized at the expense of areas within the project area more amenable to mining.

4) The dip of the section could be evaluated using triple point techniques.

Stratigraphy

The stratigrapic section mapped and drilled at Unalakleet is generalized in a section shown on Plate 6. The section at Unalakleet includes a 20 to 50 foot thick Holocene and Quaternary unit unconformably overlying an unknown thickness of Cretaceous to Tertiary terrigenous and volcanogenic sediments. The Quaternary exposures are of poorly sorted angular gravel, sand, and silt. Obvious bedding is rare; but channel cuts and rough size sorting is occasionally observed. The pebbles and cobbles are apparently derived from the Cretaceous sandstone and shale which form the hills east of the project area. Ice, occurring as accretionary wedges and as interstitial filling of void space within the Quaternary sediments is common and may be as much as 80 per cent of the total volume for any 10 foot drill hole interval. The Quaternary section is inferred to represent alluvial fan deposits shed from the local highlands.

The contact of the Quaternary and Tertiary sediments is a very irregular angular unconformity. The lowest Quaternary bed is a sandy gravel that is not significantly different from the overlying gravels.

The section exposed along the beach is a complex assemblage of unconsolidated silt, clay, coal, and ash lenses intercalated with indurated sandstones and shales. Lateral facies changes are frequent and abrupt; and few beds have a lateral extension of more than 50 feet. Low angle crossbeds (<10 degrees) are the most common sedimentary structures.

Samples collected from the rotary holes also revealed a section dominated by silt and clay. With the exception of DH-U7-83 which yielded red, brown, pink, and green interlaminated sediments, the section was a monotonous collection of grey and brown clayey silt.

The coal exposures along the beach vary in both grade and size. Discontinuous lenticular beds of clay and lignite are common along the beach. Less common thin horizons of apparently higher rank coal occur throughout the Tertiary section. Beds are rarely traceable for more than a few tens of feet and are seldom thicker then 1-2 feet. Clay beds underlying the coal horizons were common. Plant fossils were abundant in the coal and shale beds of the Tertiary section.

Samples of coal from DH-U1-83 and DH-U11-83 were collected. The intercept from DH-U1-83 was the largest coal bed found by the drilling effort. This coal bed is approximately 2 feet thick and occurs at a depth of 87 feet. The coal chips from this bed contained vitrain and plant fragments.

Coal float is not found in any of the project area streams. Several of the streams north of the project area contain abundant float; no exposures of coal were identified.

Structure

The attitude of the Tertiary to Cretaceous section was measured by direct observation of beach outcrop and unslumped bluff exposures, and by triple point analysis of drill intercepts. Partly because of the change in dip caused by slumping, previous mapping has shown the Tertiary section as dipping either west, east, or horizontal. Careful mapping of slumped areas in addition to detailed mapping of beach outcrop at low tide has shown that the Tertiary sediments within and adjacent to the project area strike approximately N 40 degrees E and dip 30-50 degrees east.

An attempt was made to do a triple point analysis on coal horizons from drill holes DH-1-83, DH-11-83, and DH-12-83. The results were ambiguous because of the discontinuous nature of the coal lenses, but a dip between 40 and 45 degrees to the east is most likely.

Aside from the faulting related to slope failure, no major faults were recognized as cutting the project area section. No direct evidence of deformation caused by the nearby Kaltag fault was observed. However, the Tertiary section was significantly disturbed by post depositional dewatering which caused severe soft sediment deformation. In many places beds are virtually squirted along small fault planes or deformed around more resistant beds.

Depositional Environment

The environment of deposition of the Tertiary section at Unalakleet is inferred to represent the marginal marine, distributary system of a lower delta plain environment. The environment was probably very similar to that represented at Koyuk. Like the section at Koyuk the Unalakleet environment of deposition suggests that significant coal deposition is unlikely anywhere within this environmental facies. It is, however, possible that environments adjacent to the distributary system and in general more marginal to the active delta may have significant coal potential.

Coal Resources

The largest lens of coal exposed along the beach is located at the mouth of Coal Mine Creek, just south of the project area boundary. The coal (clayey lignite) occurs in a pod 6 feet wide and some 20 feet in lateral extent. The lens is part of a coal horizon containing some higher grade coal that pinches out along a strike length of 150 feet. The bed dips approximately 35 degrees to the east.

Coal intercepts from the 12 drill holes were thin and deep; the thickest intercepts were no more than 2 feet. No continuous coal bearing horizons were identified. DH-U4-83 was drilled up-section from the largest surface occurrence on Coal Mine Creek to a depth of 210 feet and encountered no coal.

Conclusions and Recommendations

The Unalakleet project resulted in the definition of the study area as an unfavorable environmental setting for economic coal deposition. It is improbable that any economic coal seams will be found in deposits associated with the section evaluated.

Additionally, the Tertiary section away from the beach is covered by a prohibitively thick (>30 feet) blanket of permafrost-rich Quaternary gravel.

The occurrence of the coal beds along the beach and the presence of float in local streams indicate that, given the proper environmental setting, the existence of significant coal deposits is possible. Exploration in adjacent time-stratigraphic units equivalent to the one studied is suggested. It is still possible that other coal-bearing sections unrelated to the project area but proximal to Unalakleet may prove to be workable. To identify such coal-bearing sections it will be necessary to prospect for favorable depositional environments, thin overburden, and favorable structure. Possible sites for future exploration include areas around the margin of the basin containing the Unalakleet project area. Other occurrences in the Unalakleet vicinity should be examined, including the section of Tertiary(?) rocks some 40 miles up the Unalakleet River on the Ulukuk River (Gassay and Abramson, 1978). Local residents may be of assistance in locating other such coal occurrences.

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APPENDIX A

Geophysical Investigations

Summary

Geophysical investigations were conducted at the Chicago Creek site from August 11 through August 25, 1983. Preliminary data reduction and evaluation was conducted in the same period. Results obtained from the preliminary data evaluation were used to modify the field approach as the program progressed. The geophysical studies at this site provided mixed results; seismic reflection and EM investigations yielded little useful information on the coal unit whereas the magnetometer survey was able to discern what appears to be magnetically contrasting strata from the coal bearing sequence.

The signature of these magnetically contrasting strata could be followed between traverses along a generally northerly strike for a considerable distance (6,800 feet). Although the coal unit was not specifically identified, the anomalous pattern was consistent with data derived from the drill holes suggesting that the sequence containing the coal is identifiable and can be followed.

Introduction

The objectives of the geophysical program developed for this project were twofold: 1) to help delineate the Chicago Creek coal deposit and 2) to "test" the performance of various geophysical techniques for general applicability in permafrost terrains, particularly those with coal-bearing strata.

The approach to the program was based on methods suggested by DGGS, results of the 1982 geophysical program, and the special conditions anticipated at the site. The survey methods selected were seismic reflection, modified horizontal loop-EM, and magnetic methods which operate on a diverse set of principles. Specific tools were selected to maximize response and resolution in the permafrost terrain.

Seismic Survey

The seismic reflection survey was designed by Jerry Williams of C. C. Hawley and Associates, Inc. in cooperation with Rob Lankston of Geo-Compu-Graph (Spokane, Washington). A combination of techniques were employed to determine if seismic reflection would work. These included downhole sonic logs, refraction profiles, and an actual reflection survey.

Seismic investigations were conducted using a Geometrics model ES-1210F Nimbus 12 channel, signal enhancement seismograph. The instrument incorporates a CRT display of recorded data and produces a "hard" copy on metallic-coated paper. An array of 12 geophones was used with a spacing of 32.8 feet (10 m) between phones. Energy was supplied by small explosive charges placed at the bottom of the thawed zone. Shot point offsets of 16.4, 32.8, 114.8 and 196.9 feet (5, 10, 35 and 60 m) to the first phone were used.

Downhole sonic logs were provided by BPB Instruments using their multichannel sonic tool. Channels 2 and 3 were used to develop the velocity stratigraphy data necessary for correlation with seismic reflection results. Channel 3 is the long spacing channel and provides the best average formation velocity while channel 2, the medium spacing channel, provides more detail.

Seismic refraction and downhole sonic log data were collected and analyzed to provide the necessary velocities and velocity stratification with which to assist in interpretation of the reflection data. The seismic refraction samples indicated a surface thawed zone varying from about 2 feet to 10 feet (0.6 to 3 m) and averaging 4 feet to 5 feet (1.2 to 1.5 m) with a velocity of about 4,000 to 5,000 feet (1,220 to 1,525 m) per second.

Downhole sonic logs provided extremely valuable although discouraging data. The upper 30 feet (9.1 m) showed velocities ranging from less than 7,000 feet (2,135 m) per second to over 25,000 feet (7,620 m) per second, averaging about 11,100 feet (3,380 m) per second with 10 distinct velocity layers and significant velocity contrasts. From 30 feet to 140 feet (9.1 to 42.7 m) in depth velocities varied from about 10,000 to 20,000 feet (3,050 to 6,100 m) per second averaging about 13,500 feet (4,115 m) per second. This interval also showed significant velocity units averaging 3 to 5 feet (1.2 to 1.5 m) in vertical thickness. Field geophysical data is enclosed in a separate packet to the report.

In summary, a combination of adverse conditions severely reduced the value of the seismic reflection survey. These conditions included:

1) The dip of the strata to 300 feet in depth is beyond the critical angle of reflection. The dip did not flatten westward as had been previously interpreted.

2) The high frequency of reflecting horizons. These horizons were due both from massive, near-surface ice lenses and from thin variable beds deeper in the sedimentary section. Had factor #1 not been a problem, data may have been collected using averaged velocities for the zone of near-surface ice lensing.

3) Target coal depth in the area of interest was less than that required for the reflected signal to emerge from the attenuated wave train arising from the first arrival refraction path. The only useful data obtained from the reflection work that was done was a reflection consistent with the sedimentary/basement interface. The location of the attempted reflection survey is shown on Plate 4. No sedimentary stratigraphy or structure could be identified, resulting in the abandonment of further reflection work.

EM Survey

The EM survey was conducted using a Scintrex SE-88 Genie electromagnetic system. This system is designed to minimize geometrically derived errors, its measurements being based on the simultaneous transmission of two preselected and well separated frequencies. The amplitudes of the two signals are then compared at the receiver.

The electro-magnetic survey was first implemented in the southern portion of the study area with the hope of simultaneously assessing the extent of the coal unit and perhaps locating the suspected fault. Three east-west traverses and two north-south traverses were run in this area. Coil spacing was maintained at 164 feet (50 m) with readings taken at 75-foot (23 m) intervals. This configuration allows for adequate penetration and sampling rates (ratios of 112/1012 Hz and 337/1012 Hz) to evaluate the suspected targets. The resulting data indicated that there was insufficient resistivity contrast between the targets and the surrounding materials to provide an adequate signal for interpretation. Two additional east-west traverses were run on the north side of the creek using the same configuration, but only sampling at 30-foot (9.1 m) intervals, with similar non-responsive results. The basis for the lack of response in the EM signal is likely the result of the transmitter-receiver spacing required for penetration to the depth of interest. Ice lensing pervades both the coal bearing section and the overlying wind-blown sediments causing significant changes in the electrical character of the section over the very short distance required.

Comparing the Geonics EM34-3 system used in the 1982 investigations with the Scintrex SE-88 Genie system used in this study, it appears that the EM34-3 provides more useful information at the 65.6-foot (20 m) coil spacing configuration. It is also easier to operate and requires less data reduction. Although the SE-88 Genie has the capability of sensing much deeper, there is insufficient contrast in apparent resistivity at the depth required to provide additional information. This was suggested by the lack of response using the EM34-3 with a 131.2-foot (40 m) coil separation in the 1982 investigations. Whereas the penetration capability of the SE-88 Genie is much greater, there is no apparent increase in sensitivity over the EM34-3 at least under these conditions.

Magnetometer Survey

The magnetometer survey was conducted using a Geometrics model G-846 Unimag II portable proton magnetometer in the field and an identical unit as a base station. The magnetometer survey began on the south side of Chicago Creek where three east-west and five north-south traverses were run primarily with the hope of locating and tracing the suspected fault at the southern end of the study area. In addition, 12 east-west traverses were run on the north side of the creek. Stationing was maintained at 30 feet (9.1 m) intervals for all traverses. During the field data collection, a base station was maintained at the Kugruk campsite to monitor diurnal drift. The field data was corrected for the diurnal drift and smoothed by a three point running average before plotting. The corrected and smoothed data show quite good correlation of short period anomalies between successive east-west traverses, especially in the northern part of the study area. Other general trends appear on both the north-south and east-west traverses (Plate 4). General trends in the magnetometer data show on overall increase in intensity from west to east across the strike of the sedimentary deposit. A general north to south increase in intensity is also evident on the south side of Chicago Creek. The general intensity increases are interpreted as reflecting the thinning in sedimentary sequence as the basement rocks are nearer to the surface. The suspected fault terminating the coal unit south of Chicago Creek was not identified on the magnetic data.

A number of short period anomalies were identified on the east-west traverses. Several of these short period anomalies can be correlated between successive east-west traverses for a distance of at least 6,800 feet (2,073 m) north of Chicago Creek. The northerly trend displayed by the short period anamolies is consistent with the strike of the sedimentary units. Most significant is that offsets in the coal bearing sequence identified from the drill hole data between holes is also reflected by offsets in the short period magnetic anomalies. This consistent correlation between data sets strongly suggests that the source of the signal creating the short period anomalies is in the coal bearing sequence and can be used to trace the sequence containing the coal. The change in strike between DH-10-83 and DH-11-83 identified by analysis of the drilling data is also evident in the magnetometer data as a comparable change in the strike of anomaly alignment. Between DH-9-82 and DH-7-83 there is a noticeable offset in the alignment of magnetic anomalies. This area is also anomalous in the interpretation of the drilling data and may suggest the presence of a fault or flexure in the coal bearing sequence. Other apparent dislocations and/or flexures are suggested by anomaly correlation of magnetic data in the southern portion of the area. These other correlations are not as well defined as those to the north, however, and do not have sufficient geological support for accurate correlation. The short period anomalies change character at the southern end of the study area where metamorphic rocks were encountered at a shallow depth in the 1982 drilling program. This change in character further suggests that the short period anomalies exhibited to the north are due to the coal bearing stratigraphy. Although the coal unit was not specifically identified, the associated anomalous sequence shows promise as a marker section with which to trace the package containing the coal (Plate 4).

Conclusions

Seismic reflection, EM and magnetometer surveys were implemented at the Chicago Creek site to assess the utility of these techniques in prospecting for coal and employing them for that purpose if they showed promise.

Seismic reflection proved to be inadequate due to the combination of adverse conditions discussed above. The 1982 EM survey showed reasonable results for the shallow subsurface; however, conditions at depth restricted sufficient resolution to below interpretation levels in both the 1982 and the present studies. Magnetometer data showed similar anomalous patterns traceable from one traverse to another along a generally northerly strike consistent with known structure at the site. This correlation of magnetic data with geologic knowledge offers good prospects for extending the limits of the coal occurrence in future work at the Chicago Creek site. General trends in the data appear to arise from a deeper source than the target coal deposit and may relate to the geometry of sedimentary/basement interface.

Future geophysical studies at the Chicago Creek site could incorporate a magnetometer survey to extend the limits of the coal package and possibly to locate the suspected offset section at the south end of the known deposit. A secondary EM34-3 survey using the 65.6 feet (20 m) coil separation may be successful in identifying the subcrop of the coal unit if correlation can be maintained along strike.